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RIGIDIZED INFLATABLE SOLAR ENERGY CONCENTRATOR

First Quarterly Report

August - November 1963

AEROSPACE GROUP

HUGHES

HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

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RIGIDIZED INFLATABLE SOLAR ENERGY CONCENTRATORS

Period of August to November 1963

by

S. Schwartz

FIRST QUARTERLY PROGRESS REPORT

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FOREWORD

This quarterly report was prepared by the Materials Technology Department at Hughes Aircraft Company under NASA Contract NAS 1-3244. The work being done consists of a determination of a technique for rigidization of an inflatable parabolic collector in a space environment. This contract is administered under the direction of the Erectable Structures Branch of the Structures Research Division, Langley Research Center, with Mr. Atwood Heath serving as Technical Representative.

This report covers work from the period 1 August 1963 to 1 November 1963.

CONTENTS

LIST OF FIGURES

ABSTRACT

16333

Evaluations are being conducted on techniques for rigidizing an inflatable parabolic solar energy collector in a space environment. The stress-relaxation method of forming the parabola is discussed, along with the distortion problems found as the result of the Mylar stresses.

Materials for adhering the Mylar film to the polyester laminate are described. It was found that polysulfide coatings in conjunction with a mechanical "lock" fabric resulted in good assembly of the Mylar to the polyester rigidizing laminate. Satisfactory optics were not obtained, however, with these assemblies. Good optical surfaces were obtained when an epoxy rigidizing laminate was used indicating that the high shrinkage of the polyester was at fault. Author

INTRODUCTION

Inflatable solar energy concentrators have a great many advantages for use in space, provided a feasible technique can be developed for their fabrication. In order to be satisfactory for use the concentrator should be light weight, capable of being packaged initially in a small volume and, in a space environment, capable of being inflated to a given figure and then rigidized to maintain this figure without further inflation.

In this program the concentrator is being made in a lenticular shape, one surface utilizing an aluminized Mylar film and the other surface a clear Mylar film. On the back of the aluminized film the rigidizable layer (a polyester-glass fabric laminate) will be applied. This layer will be initially flexible (on the ground) and in space, after inflation and exposure to ultra-violet radiation the polyester resin will automatically cure, thus permanently rigidizing the aluminized section of the collector to the desired shape.

The major problem areas in this program are threefold: (1) Developing techniques for inflating the paraboloid assembly to the correct figure, (2) Developing a rigidizable layer which will also result in an acceptable optical surface on the Mylar and (3) Developing a method of securing the rigidizable layer to the Mylar film, which normally acts as a parting film.

The specific objectives of this program are, in addition to the techniques given above; to demonstrate the erection and rigidization of a five foot diameter packaged paraboloid, and to deliver to NASA one rigidized paraboloid for test. A number of mechanical, thermal, radiation and optical tests will also be made on rigidized paraboloid sections to determine resistance to the space environment, mechanical properties, and specular reflectivity of the surface.

FORMING TECHNIQUES

The technique used in forming the paraboloid is one which was developed to eliminate the need for a form so it would be readily usable for fabricating very large parabolas. In this method, known as the stress-relaxation process, a Mylar membrane is first stressed, in a fixture by internal pressurization, to a curvature in excess of the final value required. The membrane is kept in the "overstretched" condition for a short period of time after which the pressure can be released. On repressurizing to a known, experimentally determined lower value, the membrane assumes the desired parabolic curvature. The rigidizing layer is then applied to the convex surface of the Mylar after the initial stretching. Rigidization then takes place automatically on exposure to ultra-violet radiation, while the membrane is maintained at the lower pressure.

In the first exploratory tests which were made with a one foot diameter fixture and two mil aluminized Mylar an initial pressure of 105 mm Hg was used followed by a relaxed pressure of 80 mm Hg. A six layer #112 glass fabric-polyester resin laminate was applied to the convex surface of the Mylar and allowed to cure at room temperature and pressure. On removal of the rigidized part from the fixture the residual stresses in the Mylar caused severe part distortion to take place and the Mylar film delaminated extensively from the backing. Where delamination did not take place the optical surface was also relatively poor. (When the Mylar was removed completely the polyester laminate regained its original parabolic shape and showed very little signs of distortion, thus indicating conclusively that the distortion was due to stresses in the Mylar.) Additional analysis then indicated that initial stressing to 205 mm Hg and a relaxation to 62 mm Hg would also result in the desired parabola. A second laminate made in this manner showed slightly less distortion and slightly less delamination and and equally poor surface.

The results of the preliminary tests then indicated that there were considerably more stresses in the Mylar than had been anticipated, as evidenced by the distortion of the rigidized parabola upon removal from the jig. The poor adhesion of the Mylar to the rigidizing layer was not unexpected since Mylar is normally a parting agent and polyester resins usually exhibit poor adhesion.

The rigidizing fabric layers applied to the inflated parabola consisted initially of six layers of #112 fabric, a material with a weight of approximately 2.1 oz. per sq. yd., and later two layers of #181 fabric, a material with a nominal weight of 8.9 oz. per sq. yd. When combined with an equal weight of resin the rigidizing layer was approximately the calculated weight. While a thicker laminate could have been applied to help prevent the forming stress distortion, it was felt this would not be a satisfactory solution. Additional tests were then made using the same number of reinforcing layers, but in addition incorporating a circular rim around the parabola. This rim was made of resin impregnated fiberglass cord 1/4 or 3/8 inch in diameter. With the incorporation of the rim very little part distortion was encountered. Delamination of the Mylar, poor polyester laminate adhesion and a relatively poor optical surface continued to be a problem.

MYLAR ADHESION TESTS

Since the preliminary tests definitely indicated the need for improved adhesion between the Mylar and the reinforcing laminate the next efforts were directed toward this objective. It was believed that the best method of improving the adhesion to the Mylar, and also the optical surface, would be to provide an intermediate coating or coatings between the Mylar and the polyester. Such a coating, or coating combination, would act as a primer coat to improve the adhesion and at the same time, if thick enough, act as a gel coat to compensate for the shrinkage effects of the polyester-fiberglass laminate. In the event that the gel coat functioned as conventional gel coats do with polyester laminates then the optical properties would be improved.

The required properties for a primer-gel coat combination are as follows: (1) good adhesion to Mylar and to the polyester resin, (2) good flexibility in the cured state, (3) ability to be spread in a fairly thick, even coating, and (4) resistance to the space environment. Regarded as desirable, but not absolutely necessary, was the ability to dry or cure at room temperature. With the establishment of these requirements then a number of types of materials were tested. These materials included urethanes, modified polyester adhesives, modified synthetic rubber, a flexible epoxy, a flexible polyester, a silicone RTV rubber, and several polysulfides. In all cases the coatings were tested first for their efficiency in adhering to Mylar and then as undercoats for the polyester laminate. In some cases, where a coating showed promise as a Mylar adhesive, but could not be built up sufficiently to function as a good gel coat, a combination of two coatings was tested. The materials tested and the results secured are shown in Table I.

As shown in Table I there were only a few materials which met the requirements given above. Some of the first materials considered promising were the two Mylar adhesives from DuPont. Both of these materials showed good adhesion to the Mylar, however, very inconsistent bonding was obtained when the polyester laminate was put in contact with either coating. After a number of tests it was determined that both materials were being attacked by the styrene in the wet polyester laminate. In an effort to use these materials they were applied as thin primer coats and then thicker coats of either the #982 urethane, the Epo-Tuf 37-51 and the #980 polysulfide were applied to act as a gel coat. In no case was really good polyester laminate adhesion secured. However, it was considered that the problem of adhesion to the Mylar could be satisfactorily resolved. Figure 1 shows typical delamination of a primer and gel coated Mylar from the polyester laminate. In this case the entire convex surface of the Mylar was coated with a layer of #46960

Material	Source	Adhesion		Optical Surface	Remarks
		Mylar	Polyester		
52 H-192 (urethane)	International Coatings Corp., Compton, Calif.	Good	Poor	Poor	Difficult to spread to an even thick film by brush. Sprayed well.
Q-9-0090 (RTV Silicone)	Dow Corning Corp., Midland, Mich.	Good	Poor	Fair	Easy to make an even film by spraying. Low film strength.
#982 (urethane)	Coast Pro-Seal Los Angeles, Calif.	Poor	Poor	Fair	Easy to make a good film by brush or spray.
#46960 (polyester)	DuPont Co. Wilmington, Del.	Fair	Poor	Poor	Spreads to an even film by brush. Sprays well.
#46950 (polyester)	DuPont Co. Wilmington, Del.	Good	Fair	Fair	Somewhat difficult to apply by brush. Sprays well. Attacked by polyester.
#4684 (synthetic rubber)	DuPont Co. Wilmington, Del.	Good	Poor	Poor	Brushes on well. Sprays well. Attacked by polyester.
Epo-tuf 37-51 (Flex. epoxy)	Reichold Chem. Co. White Plains, N.Y.	Poor	Fair	Fair	Not too flexible. Used silica filler to reduce shrinkage.
Vibrin #121 (Flex. polyester)	Naugatuck Chem. Co. Naugatuck, Conn.	Poor	Poor		Not too flexible. Used silica filler to reduce shrinkage.
#890 polysulfide	Coast-Proseal Los Angeles, Calif.	Good	Fair	Fair to Poor	Material spread well.
CS 3414 polysulfide	Chem. Seal Corp. Culver City, Calif.	Good	Good*	Good	Material spread well. Cured very slowly.
EC-801 polysulfide	Minn. Mining & Mfg. St. Paul, Minn.	Good	Good*	Good	Material spread well. Cured nicely in 24 hours.
EC 1239 polysulfide	Minn. Mining & Mfg. St. Paul, Minn.	Good	Good*	Fair to Good	Material spread very well. Cures well in 24 hours.

*Mechanical fabric "lock" coat was used.

Table I. Results of tests with primer and gel coats.

adhesive and then one-half of the surface was coated with #982 urethane coating as a gel coat. On removal from the forming fixture delamination commenced immediately. The #982 urethane coated surface delaminated as shown in several hours. This test was also made to determine the optical differences in the use of an unfilled vs. a filled polyester resin in the laminate. The filled polyester appears to result in somewhat better optical properties.

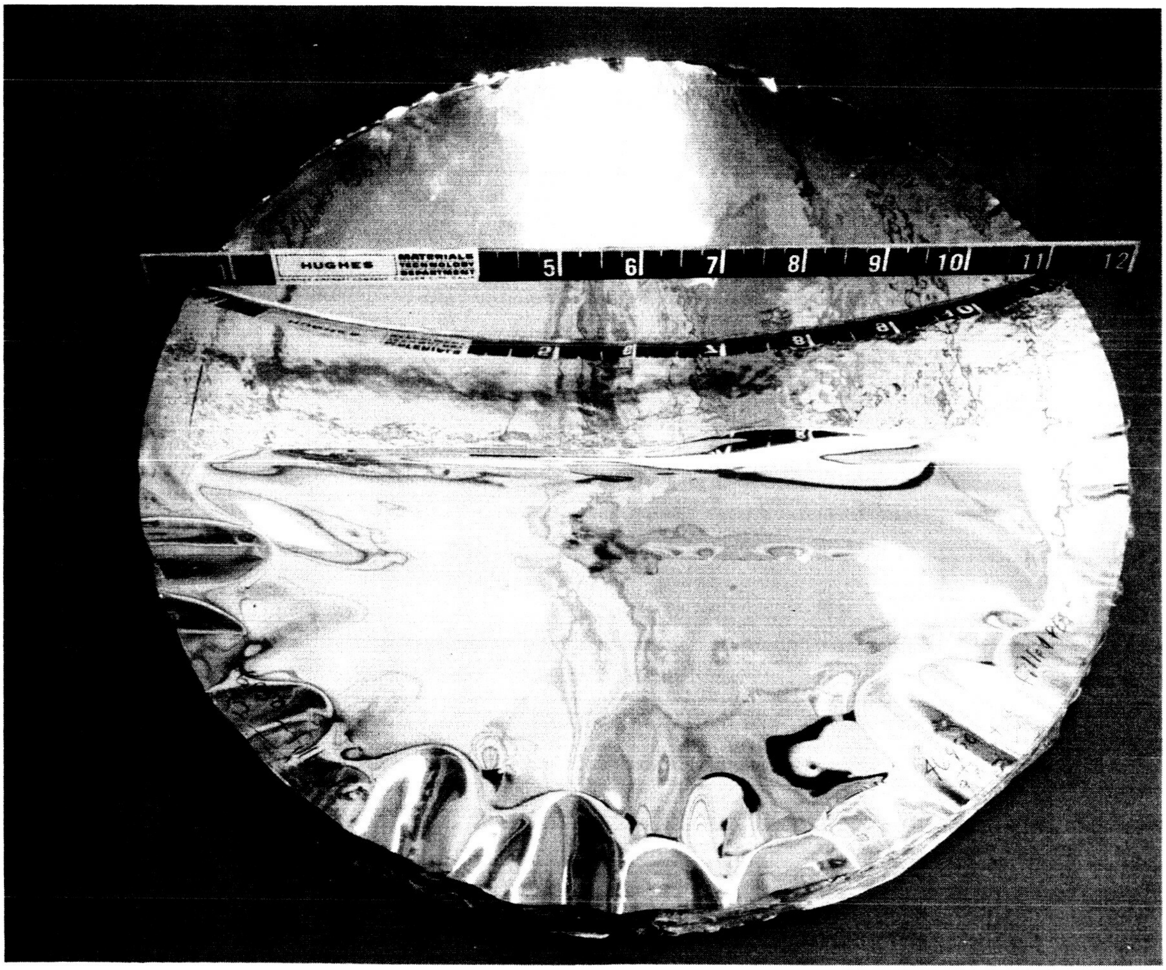

Figure 1. Typical Mylar delamination.

POLYESTER LAMINATE BONDING

The tests made with the wet polyester lay-up definitely indicated that satisfactory adhesion could not be secured when the material was in contact with any of the other cured resins. It was therefore decided that a mechanical "locking" system should be tested. The first tests were made by applying a #4684 coating to the Mylar, and when the coating was partially dried a layer of #181 glass fabric was laid on the surface. After a number of tests, to determine the right time for fabric application, it was found possible to apply the fabric so it was firmly adhered on its bottom surface to the adhesive coating, while at the same time the top surface was dry and unimpregnated. After allowing the underlying coating to cure completely the glass fabric was first impregnated with a brush coat of the filled polyester resin, then two more layers of polyester resin impregnated glass fabric were applied. Figure 2 shows the resulting configuration. The results secured with this technique were considerably more satisfactory than had been secured previously. Good adhesion of the polyester laminate to the underlying substrate was found in almost all cases.

The application of a smooth, dry glass fabric layer to a tacky surface was found to be quite difficult. Therefore a series of tests were made to determine if the solvent dried materials (#4684, 46950 and 46960) could be reactivated by simply brushing acetone over dry fabric placed on a dried coating. This technique was found to work

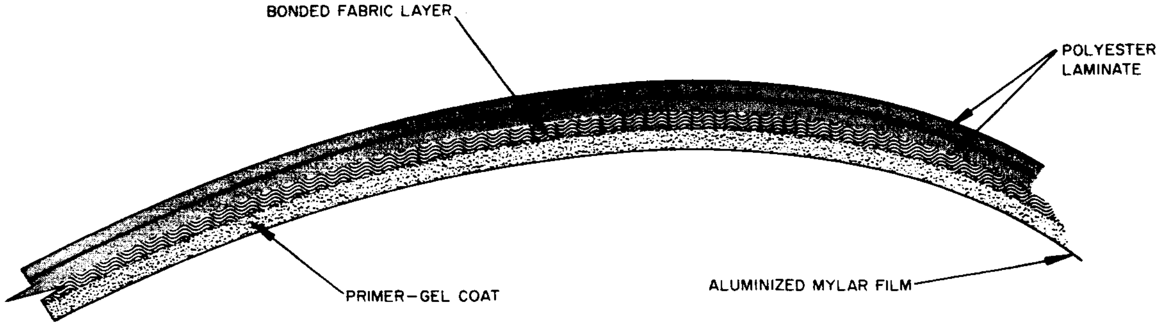

Figure 2. Cross-section of collector configuration.

very well. However, as previously stated inconsistent results were secured when the polyester laminate was applied. The cause was eventually traced to the attack on the adhesive by the styrene in the polyester used. Further work was therefore discontinued on these types of adhesives.

Tests were then run using several types of polysulfide coatings in conjunction with the mechanical "lock" fabric. Uniformly good adhesive results (Mylar-to-coating-to-polyester) were also found, as well as fair optical properties. However, with these samples a number of edge wrinkles began appearing. Figure 3 illustrates this condition. These edge wrinkles were finally eliminated by installation of more bolts in the diaphragm forming fixture. Figure 4 then shows the appearance of the best polysulfide gel coated parabola made so far. Specular reflectivity tests made of the central portion of this parabola indicated a reflectivity of 80.5%.

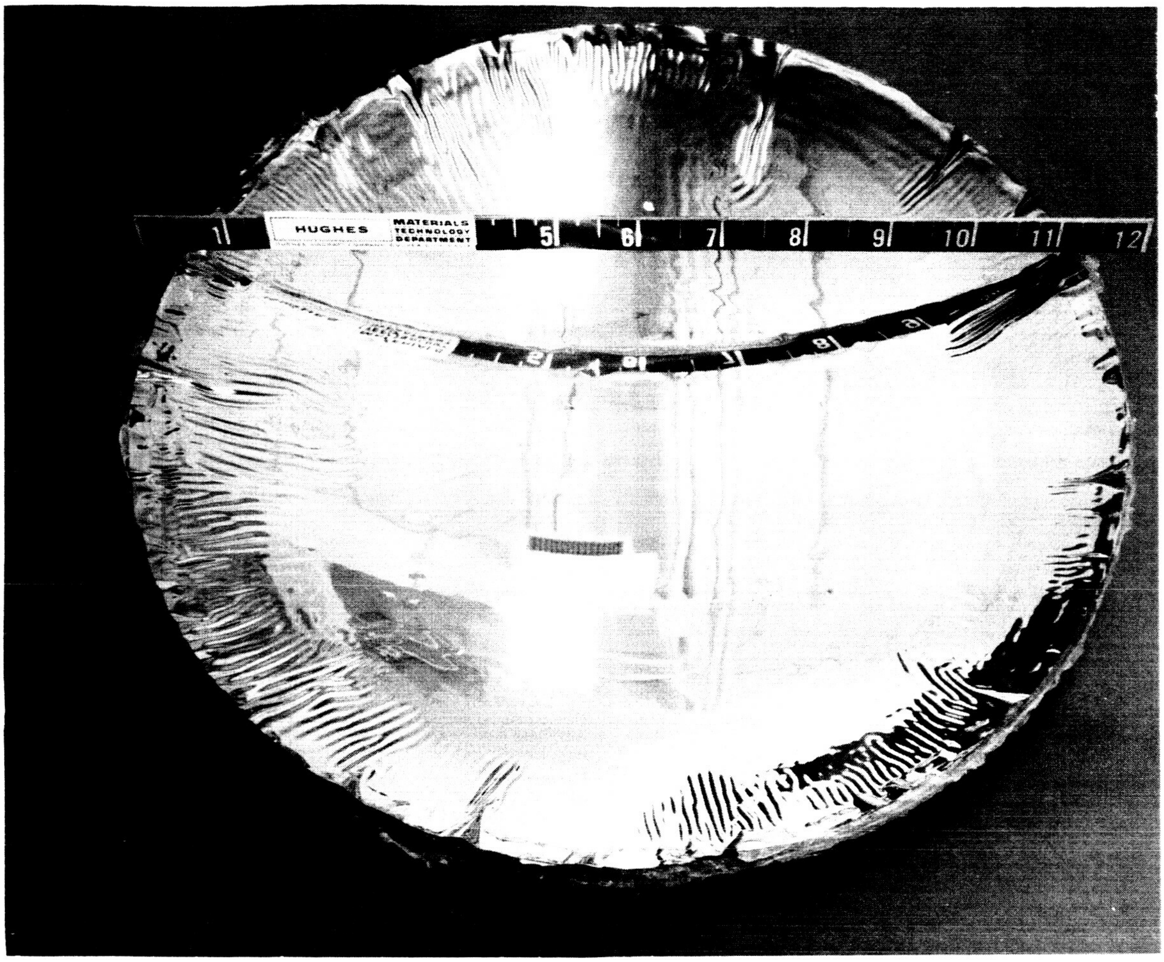

Figure 3. Edge wrinkled parabola.

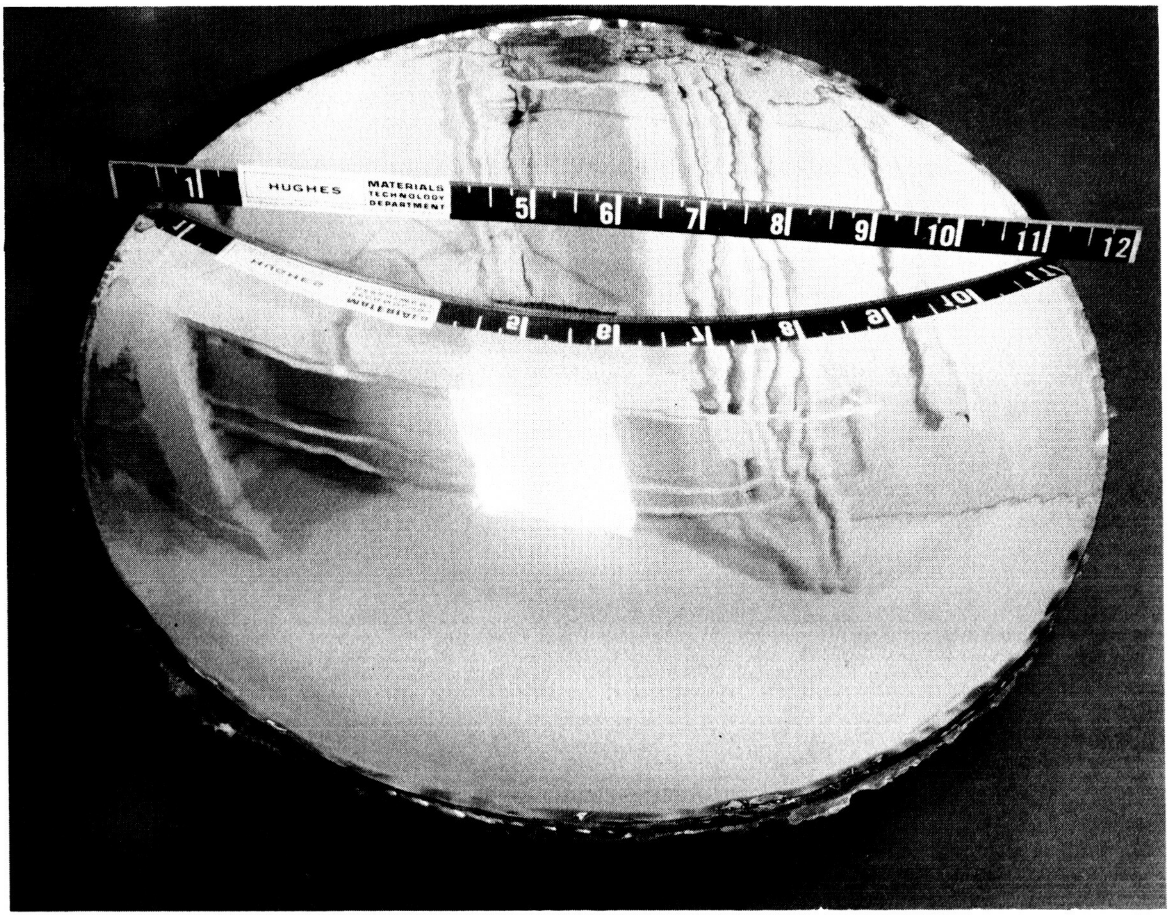

Figure 4. Polysulfide coated parabola.

TOOLING

The first samples were one foot diameter parts made as simple diaphragms in an aluminum fixture shown in Figure 5. After fabrication of the first few samples, with relatively poor optics, it was realized that using this fixture it was impossible to tell at what stage the optics deteriorated. Accordingly an acrylic window was built into the bottom plate of the fixture as shown in Figure 6. With this window it was possible then to observe the concave aluminized surface of the Mylar. Changes in the surface condition on application of each coating could then be observed. The use of this viewport then, it appeared, should aid considerably in finding the fabrication technique resulting in the best optics.

With only one fixture it took several days to fabricate each test sample, since all coatings were being cured at room temperature. Therefore, to accelerate sample production, three more small test jigs were built to make six inch diameter samples. As shown in

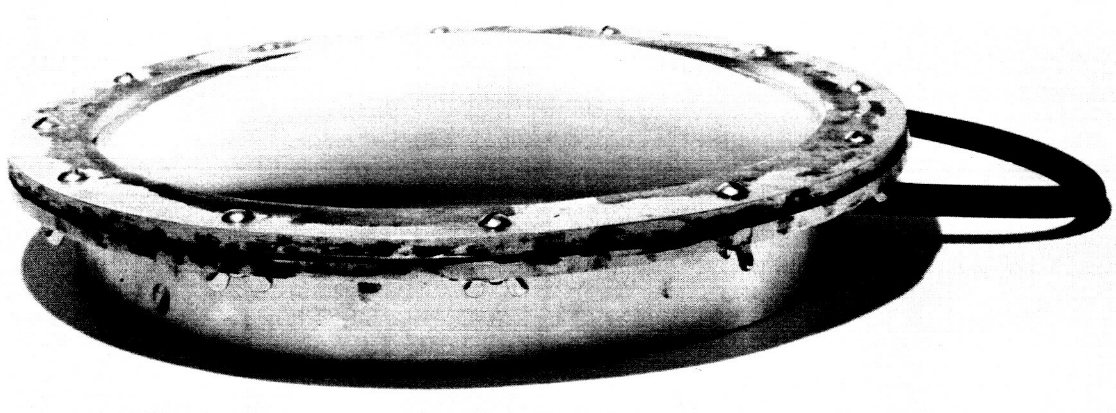

Figure 5. One foot diameter forming fixture.

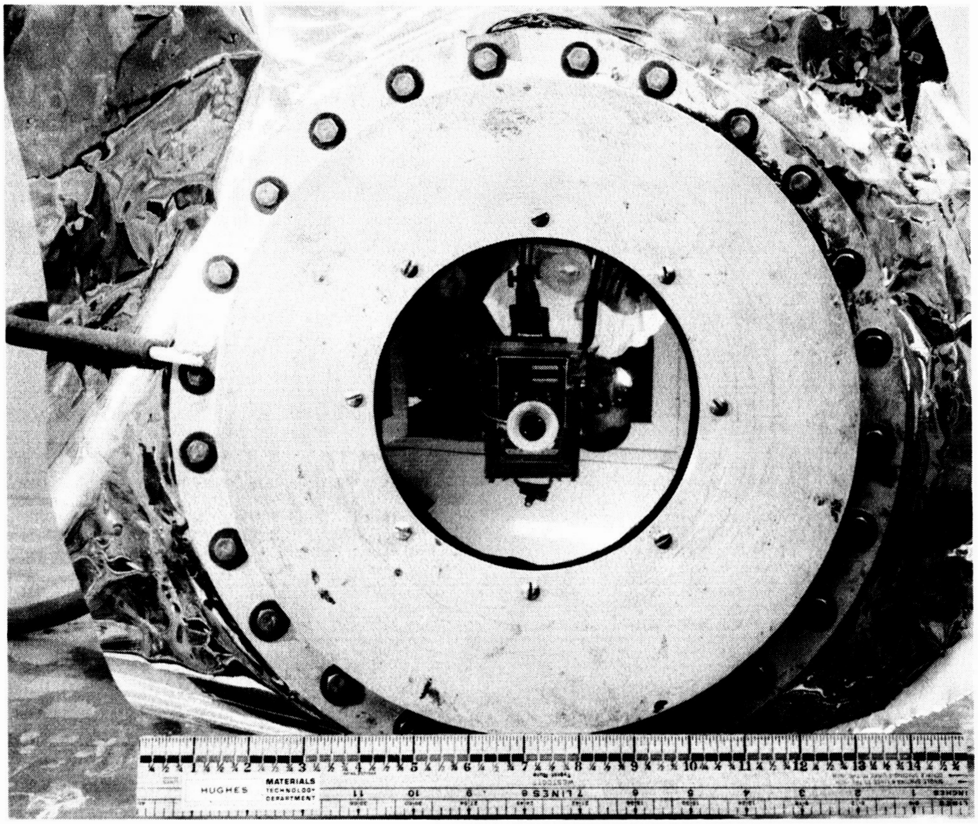

Figure 6. Window installation in the one foot fixture.

Figure 7 these fixtures were made using an acrylic block, and "O" ring and an aluminum clamp ring. With these fixtures complete transparency of the inner surface was obtained. With these fixtures then the effect of every coat applied could be immediately observed, and sufficient jigs were available so that a number of fabrication variations could be concurrently tested.

In addition to the improved small jigs a two foot diameter jig and a five foot fixture have also been designed and are under construction. Both of these fixtures will incorporate viewports so that the optical effect of each fabrication step can be observed.

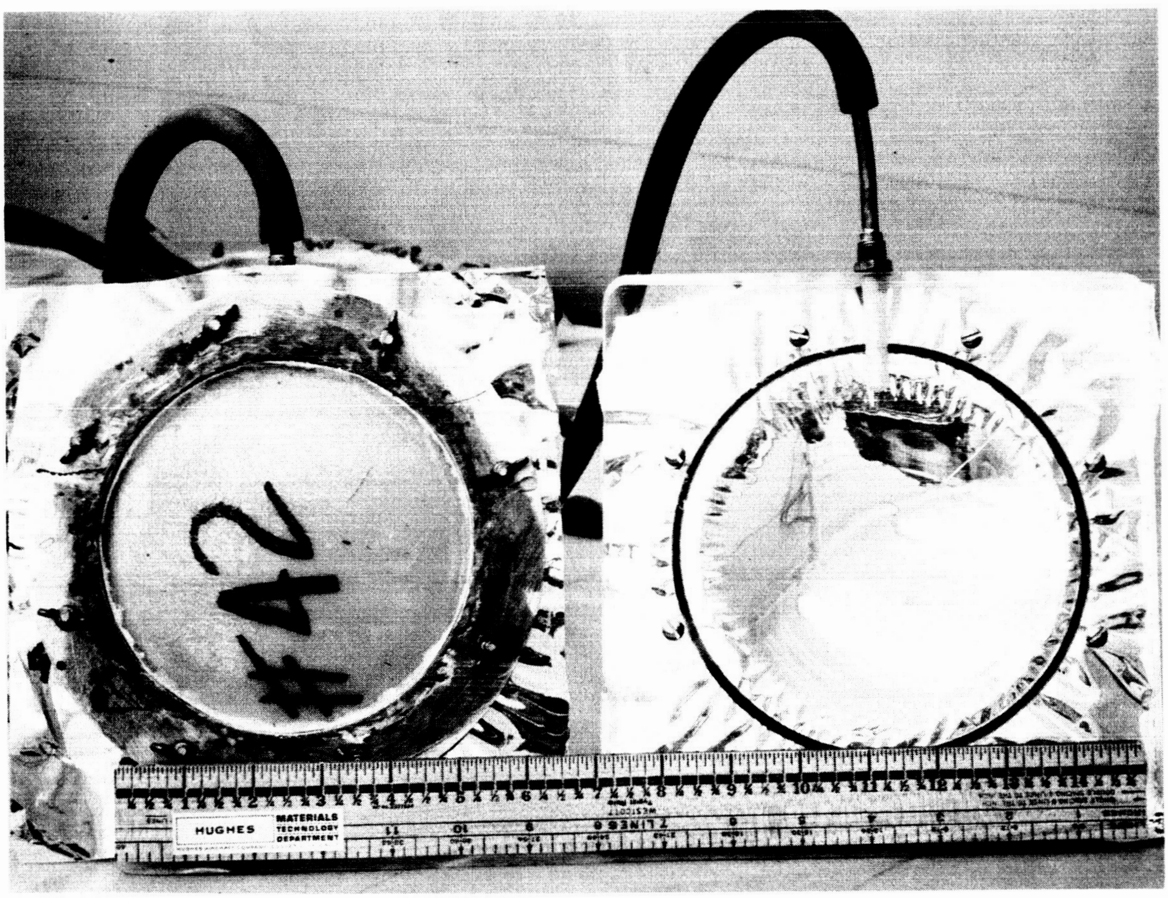

Figure 7. Transparent six inch diameter fixtures, showing both surfaces of part.

OPTICAL SURFACE TESTS

The choice of a polyester resin-glass fiber laminate for rigidizing the parabola was made because this system offers a number of advantages over other resin systems for space applications. First this system can be completely automatic, utilizing ultra-violet radiation in space for triggering the reaction. Other proposed systems such as urethanes or epoxies require vapor catalysis or heat, with attendant problems of special containers, valves, etc., and/or means for reducing the heat when the reaction is completed. The second advantage of the polyester system then is that this system should be one of minimum weight. There are also, however, two major problems concerned with the use of a polyester for this application. The first of these concerns the poor adhesion of the polyester laminate to the Mylar. The steps which were taken to solve this problem were detailed above. The other major problem of the polyesters concerns the relatively high shrinkage of the resin which is inherent in this type of material.

In the fabrication of other types of polyester-glass fabric structures shrinkage is shown on the surface of a part as an optical phenomena in which the resin shrinks back into the glass during cure, thus resulting in surface showing a fabric pattern. (This pattern would be unacceptable for a reflector surface.) The usual method for eliminating this effect is to use a heavily filler loaded polyester gel coat next to the mold, on top of which the polyester laminate is laid. The gel coat then becomes the outer surface of the part. This general technique then is the one which is being investigated to minimize these surface defects from appearing on the aluminized Mylar. The application of this principle, however, is complicated by the fact that the mold in this instance is not a rigid body as is the usual case, and the fact that the gel coat must be very flexible after cure, rather than a hard, rigid coating as commonly employed.

The initial tests made to develop the rigidized parabola were mainly concentrated on the problem of obtaining satiafactory adhesion of the Mylar to the polyester laminate. During these first tests it was found, as expected, that when the polyester laminate was applied directly to the Mylar the fabric pattern was clearly visible wherever adhesion took place. The addition of silica filler to the polyester resin helped somewhat in reducing the pattern, but not markedly. In later tests when relatively heavy gel coats were used it was found that a distinct fabric pattern was no longer visible. The optical surface which was achieved ranged from nearly perfect to badly distorted. Figure 8 illustrates four different degrees of optical surfaces obtained using the gel coat-mechanical fabric "lock" techniques. It is significant to note that the two best samples, #1 and #2, were rigidized with room temperature curing epoxy coatings, rather than the polyester. These two samples were prepared as a test to determine if the patternless distortion was due to polyester shrinkage, since the epoxies exhibit considerably less shrinkage than do the polyesters.

Other evidence definitely linking the shrinkage of the polyester to the distortion was the fact that on application of the polysulfide coatings to the Mylar the concave surface optics remained perfect prior to, during the cure and after cure of the gel coat. Very little or no optical effect was noticed when the "lock" fabric was applied.

It was also found that two coats of gel coat gave better optical results than did one. The gel coat configuration then adopted consisted of one coat brushed or sprayed on and allowed to cure 24 hours, followed by a second coating. The "lock" fabric is then applied to the second coat when cure is partially completed. By this technique the possibility is avoided of the fabric showing completely through the uncured gel coat, as was found in the first experiments.

The polyester resin is applied to the coated parabola by first brushing one coat of filled polyester resin into the lock coat, followed by two layers of #181 glass fabric and resin. Since the resin is heavily filled (50%) to minimize shrinkage, it was found impractical to spray the resin. In observing reflections in the concave surface of the parabola during cure distortion was found to commence at approximately the same time as did gelation of the resin.

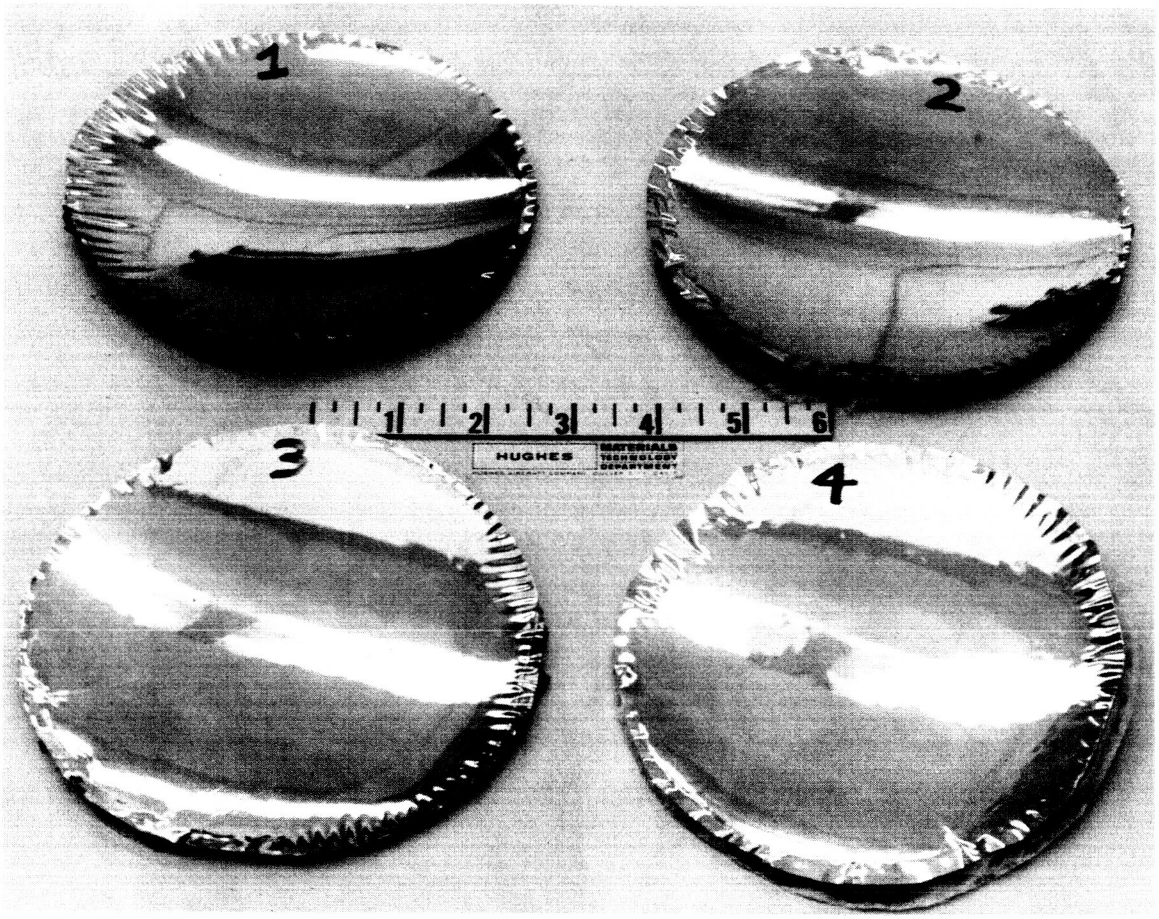

Figure 8. Varying degrees of optical surfaces produced.

Another technique for minimizing surface defects in a polyester laminate is to use very fine weave cloth or surfacing mat on the outer surface under the heavy reinforcing fabric. These techniques were also tried, however, these materials appeared to interfere with the functioning of the "lock" fabric. #128 glass, an intermediate weight fabric, was found best from the standpoint of "lock" and minimum optical effects.

In all the above tests the polyester resin used was American Cyanamide Laminac #4128, a general purpose, styrene monomer resin. The resin was catalyzed with 1-1/2% of methyl ethyl ketone peroxide and 1/2% of cobalt napthenate to result in a room temperature gel time of approximately 30 minutes. The filler used was a 99.9% pure silica and was mixed in the ratio of 1:1 with the resin to give maximum shrinkage reduction, without too much effect on mechanical properties. The above resin was used mainly for convenience in preparing samples at room temperature and pressure. Tests, however, were made to determine if such a heavily filled resin would cure satisfactorily by U.V. These tests indicated that a satisfactory cure could be obtained.

FUTURE PLANS

For the next quarter it is planned that the following items will be investigated:

1. Gel coats formulated from Versamid-epoxy mixtures and from polysulfide-epoxy-mixtures will be made. These materials will be tested for adherence to the polyester laminate with the possibility of eliminating the fabric lock coat.

2. An investigation will be made into polyester resins which exhibit lower shrinkage. One such to be investigated will be resins utilizing diallyl phthalate monomer, which are claimed to have 30% less shrinkage than conventional styrene monomer resins. Other similar resins are said to be in development.

3. Tests will be initiated to determine the mechanical, optical and space environment resistance properties of the assemblies found to result in good optics.

4. Preliminary tests will be started on the five foot parabola to determine pressures required and coating techniques.

5. It is planned to spend a small amount of time investigating the possible use of an epoxy or a urethane system for rigidization. Such systems are currently being developed on other contracts at Hughes Aircraft Company.